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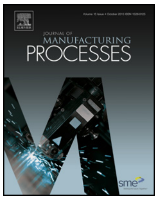

Technical Paper

Material and process optimization screen printing carbon graphite pastes for mass production of heating elements

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ABSTRACT

An experimental development programme has been carried out for the production of resistive heated panels to be used in raised access flooring. Screen printing was used as the means of depositing the heating element and the paper examines the means by which the process is optimised from assessment of material formulations through to a pilot production run of 300 tiles. A material with a sheet resistance of 35 Ω/sq, when printed through a 77-48 polyester mesh was selected by examining its rheological and drying behaviour. Higher film thickness with coarser screens was not possible as this incurred topological variations in the printed film and required excessive drying times. During a pilot manufacturing run of 300 panels, process drift was observed and this was attributed to squeegee softening due to solvent absorption. The generic findings of the study are applicable to many applications where screen printing is used for the continuous deposition of materials where the characteristics of the deposit and its subsequent curing is paramount such as sensor, third generation PV and circuit boards.

1. Introduction

Resistive heating through the floor provides a practical means by which energy can be supplied for temperature control within the build environment. It promises many advantages over "wet" (boiler and radiator) systems in that can be more readily controlled, it can be localised, it has lower ongoing maintenance costs, it provides improved occupant wellness, it can be installed in a shorter time and provides install flexibility. In the commercial and retail build environment, the dominant flooring design is based around raised access floor (RAF) tiles where individual floor tiles ($600 \times 600\,\text{mm}^2$) are arranged in a grid resting on pedestals, which maintain the tile a fixed distance from a base floor. The floor tile consists of a chip board wooden board (25–75 mm in thickness) which is laminated between two coated steel sheets. The void between the floor tile and base floor is used for services such as electrical power and water distribution. Incorporation of modular heating elements within the RAF tile on the upper steel surface offers commercial promise as it marries the flexibility of electrical heating with a high volume (3 million tiles in UK alone) standardised product. The large area, volume and thin form factor of the product provides an ideal opportunity for thin film resistive heating elements (Fig. 1) [1].

In order to meet the expected demand, a manufacturing process was required which placed the conductive element on the underside of the coated steel material in contact with the adhesive. The conductive element therefore needed to be thin (no thicker than 200 μm of adhesive), be compatible with the adhesive, able to withstand operational compression forces and be compatible with high volume manufacturing. Such requirements lend themselves to printed conductive structures where percolation between conductive particles embedded within a polymer binder and solvent are deposited and cured.

Screen printing was deployed as the manufacturing process of choice as the process is mature, materials are commercially available, it has a low capital cost and is able to deposit a thick film capable of carrying the currents necessary for effective heat generation. In screen printing, transfer of material to the substrate is effected by the passage of a squeegee across the screen which places the screen in contact with the substrate (Fig. 2a). The primary dictator of film thickness is the mesh structure as it holds the quantity of paste which is available in the mesh for transfer (Fig. 2(b)).

Commercial conductive materials contain silver, carbon or gold as the conductive element within a polymer/solvent blend and the choice of these elements and their ratios being dependent on conductivity requirements, adhesion, ease of processing, economics,

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Abbreviations: BOM, Bill of materials; RAF, Raised access flooring.

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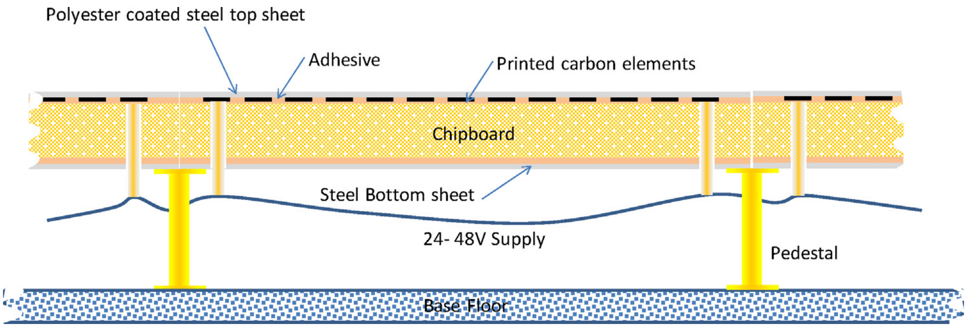

Fig. 1. Schematic of RAF floor tile fitted with a heated panel.

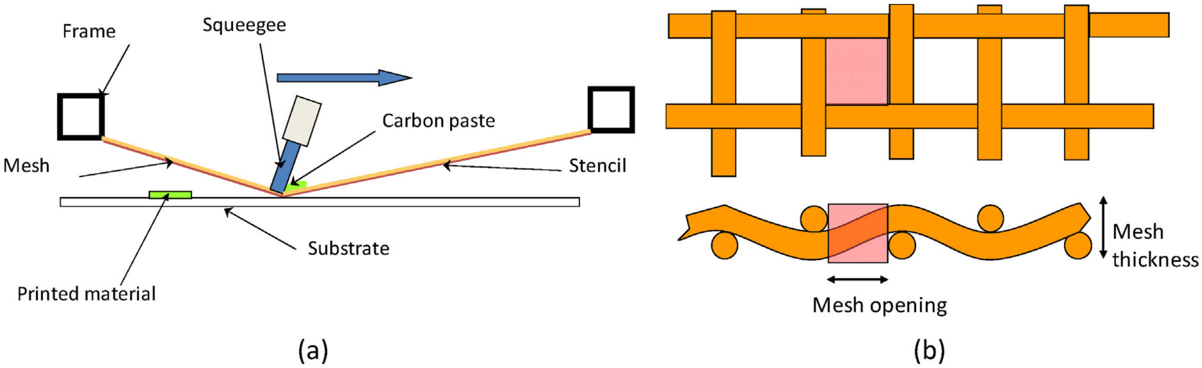

Fig. 2. (a) A schematic of the screen printing process and (b) mesh characteristics on material available for transfer to the substrate.

substrate flexibility and curing conditions. Applying the technical and economic requirements for the dissipation of 200 W/m^2 and manufacturing volume required, then conductive carbon materials were selected. These carbon paste materials are predominantly deposited by screen printing, although few systematic studies on its uses for continuous manufacture are available in the public domain.

The use of carbon as a material for underfloor heating is well established on flexible and rigid substrates. These conventionally operate at high voltages (>100 V AC) and thus the requirements for highly conductive structures and materials can be relaxed as the high voltage maintains an appropriate current flow through the resistive track even at high track resistances. In order to be compatible with future DC building developments [2,3] and local photovoltaic generated electricity, the electrical circuitry was designed with operation at in the 24–48 V range. This requires a lower circuit resistance and subsequent tighter tolerances from nominal specifications. These requirements dictate higher performance materials and a robust manufacturing method.

By far the dominant use for carbon paste in terms of number of applications is its use for electrochemical sensors and their used in this field is well documented [4]. Carbon materials have also been used for counter-electrodes in DSSC [5,6,7], super-capacitors [8] and sensors for physical characteristics such as strain [9]. With the advent of more advanced materials such as carbon nano tubes and graphene, fundamental and applied studies into carbon/graphite based materials for resistive applications have been limited. Carbon black/graphite screen printing materials are considered commercially mature, although this work will show that there is considerable variation in their performance.

The most relevant technical information is derived from the use of printed carbon materials for passive elements in the PCB industry. The structure and relative content of the carbon black/graphite is a dominant factor in determining electrical performance (usually characterised in terms of sheet resistance) [10,11,12]. The means by which the particles orientate themselves during transfer also plays a key role in determining electrical performance as these impact the percolation through the film [13]. When carbon/graphite materials are screen printed, sheet resistances are typically between 10 and 500 Ω/sq depending on carbon loading and film thickness [12,14]. This range is compatible with the circuit and application requirements.

The aim of the study was to optimise the printed heated element production process through a scientific study of material properties, the manufacturing process and their interactions. This would deliver an efficient and economic manufacturing process developed through logical rationale and scientific understanding. The first step in the study was to examine the performance of commercial materials to identify those with most promising electrical and processing performance, then to examine process parameters to establish the means by which a film can be repeatedly deposited and cured as required by a controlled manufacturing process.

2. Methodology

Printing was carried out on a ATMA 1014 screen printer with drying taking place in 3 m long Thieme tunnel dryer operating at 1.2 m/min (residence time of 2.5 min) at an air temperature of 155 °C. This equates to maximum substrate temperature of approximately 150 °C. The transfer speed through the dryer was determined as the minimum speed for a balanced production line. Although this condition was used as a standard, any reduction in temperature and dryer residence time would have a positive effect on the operational costs and process throughput. The conductive materials were printed to a 600 × 600 × 0.7 mm^3 (width × depth × thickness) polymer coated steel (TATA “Prisma”) substrate which was textured with a roughness R_a of approximately 2 μm. The substrate was chosen as it has been developed for corrosion resistance and the organic coating is guaranteed pinhole free, a prerequisite to prevent circuit/substrate shorting.